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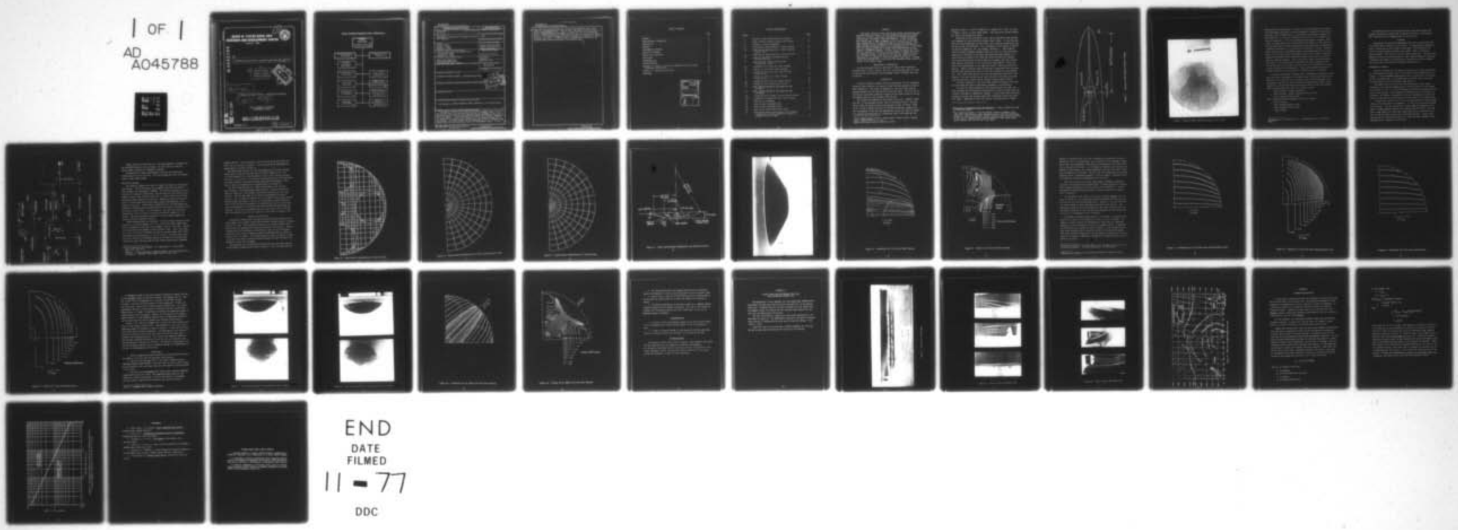

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

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by

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David W. Coder,
Raymond J. Grady
Richard M. Norton

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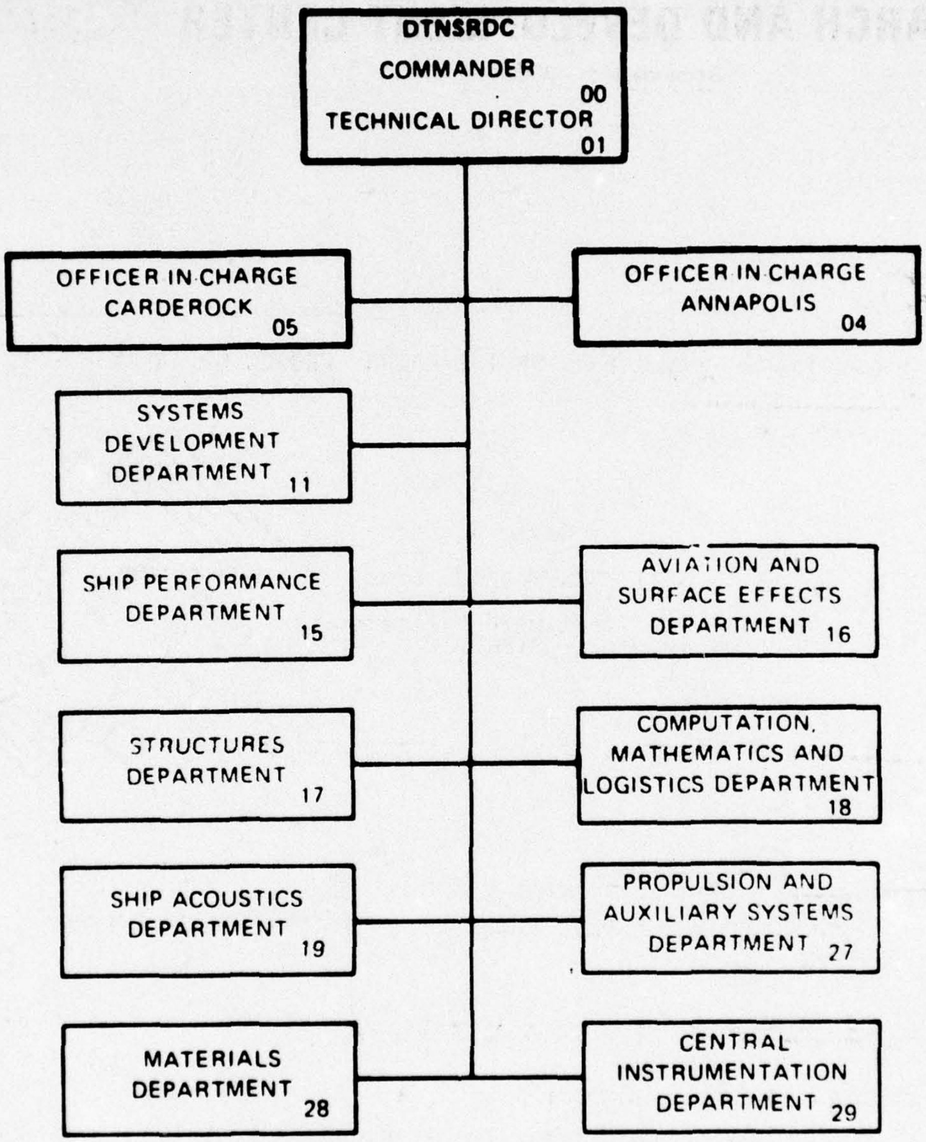

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The Sperry Projector Array housing and several modifications were evaluated using the Center's 36-Inch Variable pressure water tunnel (from 4 to 16 knots) and using a potential-flow computer program (XYZ-PFP) and the Center's CDC 6700 computer. It was conjectured that bubbles due to bubble sweepdown or air coming out of solution were accumulating in the separated region aft of the housing. This might account for the broadening of the aft projector beam pattern which had been determined from at-sea performance trials. It was → next page

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shown that the original design had a rather large separated region which tended to accumulate bubbles. Suction, aft of the model, up to the rate of 7 gal/min ($4.4 \times 10^{-4} m^3/s$) did not appear to change the size of the separated region. Rotating the array 45 deg around a vertical axis did help to reduce the size of the separated region but not sufficiently to eliminate it from the projector lens faces. A large housing was designed which should move the separated region beyond the region of the acoustic beam.

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ABSTRACT

The Sperry Projector Array housing and several modifications were evaluated using the Center's 36-Inch variable pressure water tunnel (from 4 to 16 knots) and using a potential-flow computer program (XYZ-PFP) and the Center's CDC 6700 computer. It was conjectured that bubbles due to bubble sweepdown or air coming out of solution were accumulating in the separated region aft of the housing. This might account for the broadening of the aft projector beam pattern which had been determined from at-sea performance trials. It was shown that the original design had a rather large separated region which tended to accumulate bubbles. Suction, aft of the model, up to the rate of 7 gal/min ($4.4 \times 10^{-4} m^3/s$) did not appear to change the size of the separated region. Rotating the array 45 deg around a vertical axis did help to reduce the size of the separated region but not sufficiently to eliminate it from the projector lens faces. A large housing was designed which should move the separated region beyond the region of the acoustic beam.

ADMINISTRATIVE INFORMATION

The work presented here was sponsored by Sperry Rand Corporation, Purchase Order P-171010, dated 1 June 1977, and performed under the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) Work Unit 1-1556-071.

INTRODUCTION

In order to obtain accurate velocity measurements for the navigation system of naval vehicles, an acoustic system has been proposed by Sperry Rand Corporation. The system is composed of a projector and receiver mounted athwart ship and some distance from each other. The velocity of the ship is obtained by bouncing a signal off the ocean bottom or off the surrounding water at some distance from the ship.

The system was evaluated on the bottom of the U.S.S. COMPASS ISLAND (AG 153), a flat-bottomed surface ship of the Mariner Class.[1] The projector array and receiver array were mounted at frame 74 athwart ship 52 in. (1.32m) starboard and port of the ship centerline, respectively. This arrangement on the ship and approximate outline are shown in Figure 1.* The receiver array housing is a streamlined body of EPH shape and the

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[1] Jane's Fighting Ships 1976-77, Captain John E Moore, Editor, Paulton House, London (1976-77), p. 651.

*Copied from Sperry Drawing E/13604/223-43788.

projector array is a "slice" (segment) of a sphere with "flats" as shown in Figure 2 (this is a full-scale model). The flats were located forward, aft, port, and starboard as shown.

During the at-sea evaluation trials, the aft projector beam pattern was broadened for ship velocities greater than 8 knots. It was concluded that this beam broadening was most likely due to bubbles accumulating near the face of the aft projector. For a discussion of the effect of bubbles on acoustic properties, see, for example, Reference 2. These bubbles could be caused by bubble sweepdown under the ship or by dissolved gases coming out of solution as the water experiences pressure changes as it flows around the bottom of the ship and around the projector housing. Since the aftward-facing projector beam was disturbed while the forward beam appeared unaffected, it was conjectured that bubbles, however produced, were accumulating in the separated region** behind the projector housing. Bubbles flowing around the housing or generated by the pressure field of the housing would tend to rise due to buoyancy as they proceed aft. Thus, they would tend to rise into the separated region aft of the housing. The lower velocities and vortex action of the wake area would cause the bubbles to gather there, causing a higher bubble density.

As seen in Appendix A, the flow lines around the Mariner class ship do curve under the ship so that bubble sweepdown is a possibility.

In order for bubble generation from dissolved gases to occur, the water pressure has to drop below the pressure at which the gases went into solution (assuming no temperature changes). As the water flows around the projector housing, the pressure drops with increasing velocity and rises with depth. Depending on these two factors, the possibility of bubble

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[2] Principles of Underwater Sound for Engineers, J. Urick, McGraw-Hill Book Co., New York (1967).

** The "separated region" is the wake region created by boundary layer separation. When boundary layer separation occurs, the flow streamlines instead of following the general surface contour diverge outward starting at the point of separation and continue around the wake region (which usually extends over the aft end of the body).

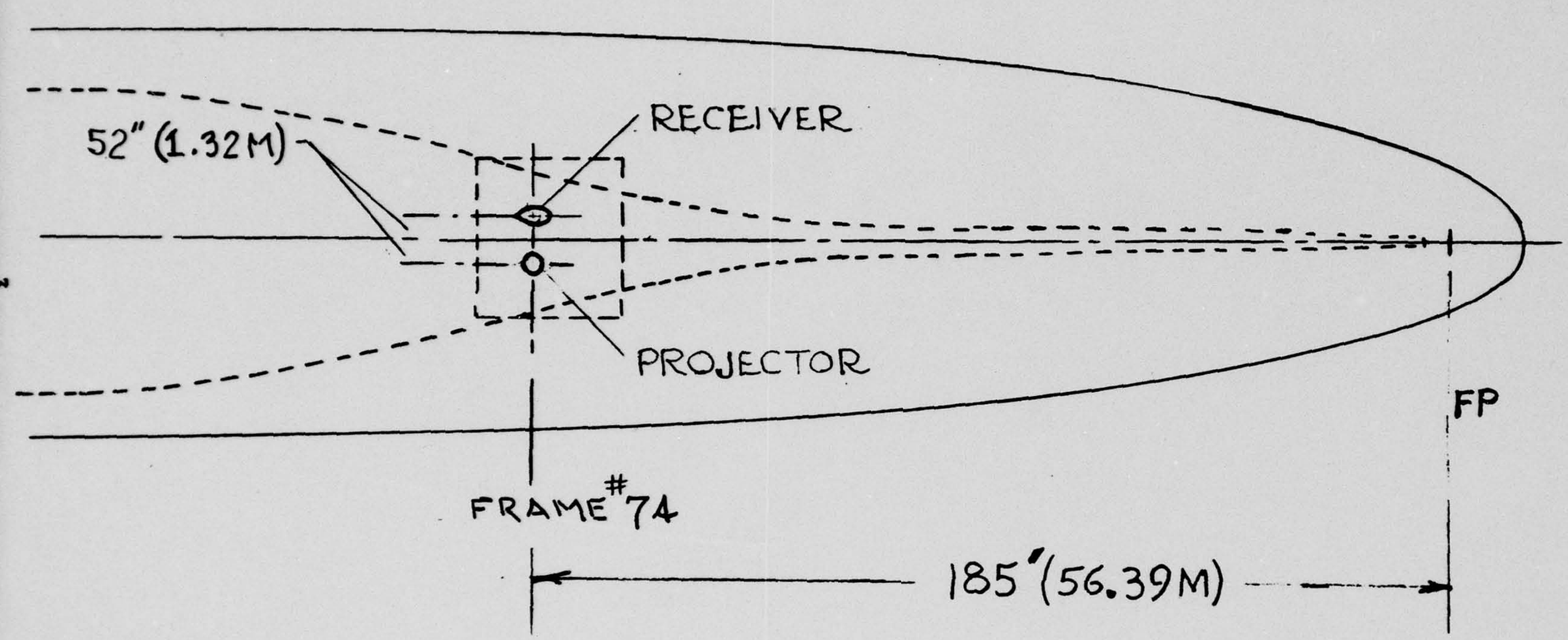

Figure 1 Outline of Ship Showing Location of Domes

Figure 2 - Model of Basic Projector Housing (Full Scale)

generation may be determined. In order to see the magnitude of the pressure disturbance necessary to obtain atmospheric pressure at the bottom of the ship, 25 ft (7.62m) depth, a calculation is presented in Appendix B. From Figure B1, at 8 knots, a pressure coefficient of -9 is needed to obtain this pressure. This is an extremely large negative pressure coefficient. In other words, near-surface water that makes it to the bottom of the ship would tend to start releasing dissolved gases when it experiences a pressure coefficient of -9 or less for a velocity of 8 knots. However, since there may be a considerable amount of dissolved gases even at keel depth, 25 ft (7.62m) in the undisturbed ocean,[3] only a small or moderate pressure disturbance could conceivably cause this water at the greater depth to yield gas bubbles. Due to the lack of data on dissolved gases with depth in the ocean and the particular flow lines around the ship (including those at a distance from the hull), it is impossible to obtain an exact analysis of the phenomenon. Thus, bubble generation from dissolved air should not be excluded as a possible source for bubbles.

In order to determine if bubbles due to sweepdown or generation could enter and stay in residence in the wake area of the projector array housing and to help point the way to possible fixes, model experiments were performed in the Center's 36-Inch variable pressure water tunnel and potential flow calculations were made using the Center's CDC 6700 computer. Three configurations were tested in the water tunnel:

- Basic housing - normal orientation
- Basic housing - normal orientation with suction
- Basic housing rotated 45 deg

Four configurations were evaluated using the computer:

- Basic housing
- Basic housing rotated 45 deg
- Basic housing without flats
- Large fairing

[3]The Oceans, H. U. Sverdrup, et. al., Prentice-Hall, Inc., New York (1942).

The remaining part of the report describes these water-tunnel and computer evaluations, presents and discusses the results, and then presents conclusions and recommendations for the best fix.

APPROACH

Experimental and analytical approaches were used to investigate the flow around Sperry Projector Array housing. The experimental approach involves visualizing the flow around a wood model of the housing in the Center's 36-Inch variable pressure water tunnel (VPWT) by injecting either nitrogen or dye into the flow to observe separation. The analytical approach utilizes an existing potential flow computer program to determine streamlines and isobars on the body and to examine whether an alternate body shape would have better hydrodynamic characteristics.

EXPERIMENTAL APPROACH

The full-size model of the Sperry Projector Array housing was mounted on a horizontal base plate in the 36-Inch VPWT as shown schematically in Figure 3. This arrangement approximates that of the array on the bottom of the flat-bottom hull. The wooden model was fitted with bolts which allowed rotation to 45 deg from the usual position.

Two tubes (ID=0.25 in.=0.64 cm), which were used to emit either nitrogen or dye solution through holes in the base plate into the stream, were located at 1-1/2 in. (3.8 cm) forward of the housing leading edge and at the trailing edge. The nitrogen was introduced into the stream to investigate the effects of bubbles in the flow. Rhodamine dye (red) solution was introduced to show primarily the wake region aft of the housing.

A larger tube (ID=0.50 in.=1.27 cm) to allow suction of fluid through a hole in the base plate was attached 1 - 1/2 in.(3.8 cm) from the housing trailing edge. This was connected to a small pump and "rotameter" flow meter. Maximum pumping capacity was 7 gal/min (4.4×10^{-4} m^3/s). This was used to pump water out of the wake region and observe the effect of suction on the wake region during dye or nitrogen ejection. Lesser rates were possible by adjusting a valve. All runs were made, however, at the maximum rate of 7 gal/min (4.4×10^{-4} m^3/s).

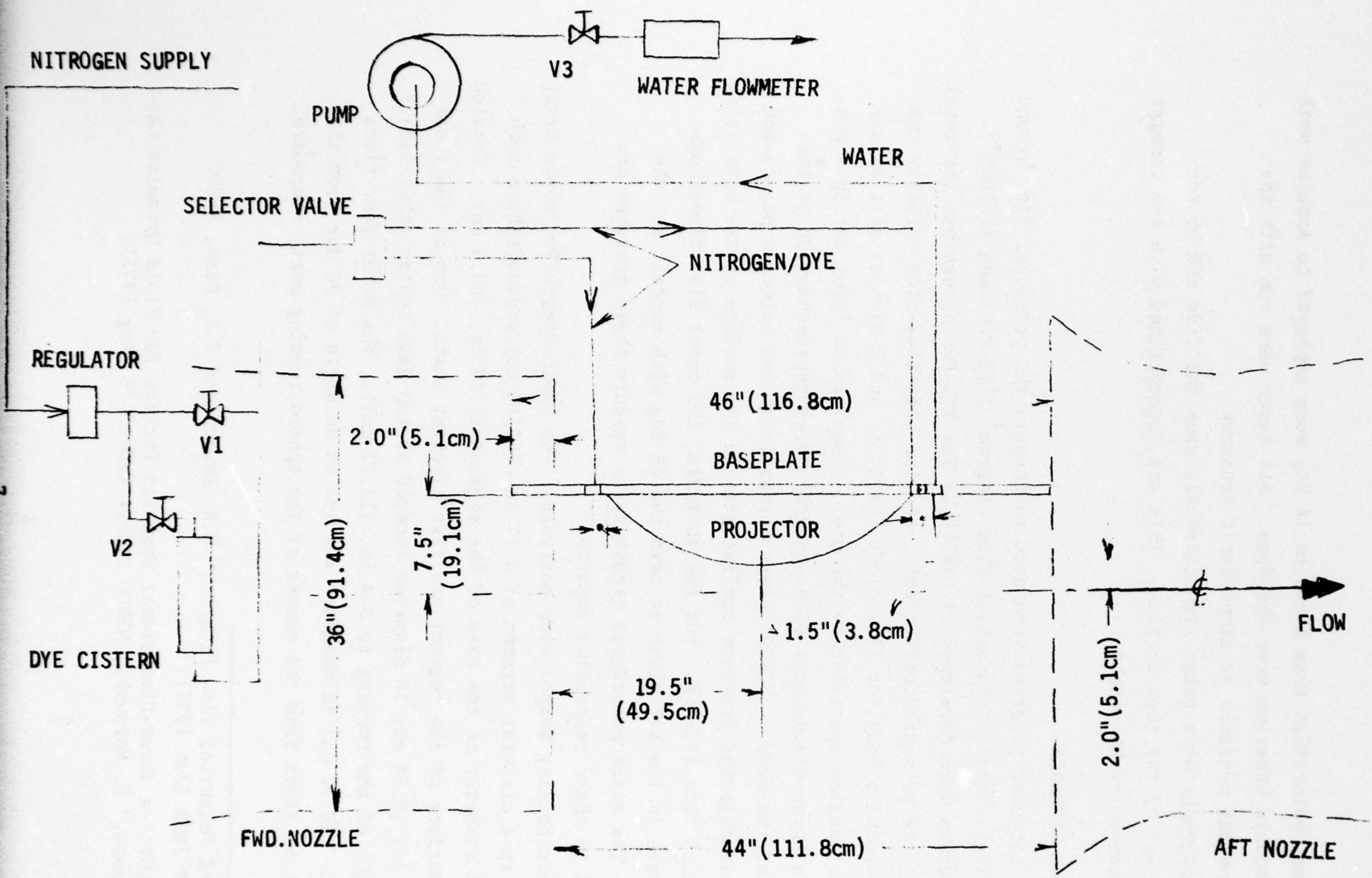

Figure 3 -Schematic of Test Arrangement

Tunnel velocities from 4 kts to 16 kts were employed to examine both dye and bubble behavior over the dome. All tests were run with the tunnel ambient pressure at atmospheric pressure.

Photographs were taken simultaneously from the side and bottom (looking up) of the test section. This was accomplished with two cameras using a common light strobe.

ANALYTICAL APPROACH

The computer programs were used to compute the potential flow around the housing -- the XYZ Potential Flow Program[4] (XYZ-PFP) and XYZPLOT[5]. Both programs were developed at DTNSRDC. The XYZ-PFP determines the total velocity, the pressure coefficients, and the potential flow velocity components around a body for flow along the X, Y, and Z axes as well as any additional angles specified by the user. Required as input for this program is a three-dimensional plane-quadrilateral representation of the surface of the body. XYZPLOT plots streamlines from selected points and isobars at selected pressure coefficients on the surface of the body using the results from XYZ-PFP. For the analysis, the onset flow directions chosen were in the X-Y plane at zero and 45 deg with respect to the X-axis. The exact procedures necessary to execute these programs are detailed in their respective reports.

Three housing shapes were analyzed. The basic Sperry Projector Array housing is a circular segment of a 17 in. (43.18 cm) radius sphere such that its diameter at the base of the segment is 25 in. (63.5 cm). Located on the surface of the segment are five circular flats. One of the flats is 3.26 in. (8.28 cm) in diameter located at top dead center (this limits the height of the housing to 5.4 in. (13.72 cm)). The other four flats are 8 in. (20.32 cm) in diameter and are at an angle of 30 deg from the vertical on lines from the center of the sphere running port, starboard,

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[4] "The XYZ Potential Flow Program," C.W. Dawson and J.S. Dean, NSRDC Report 3892 (Jun 1972).

[5] "XYZPLOT: A Three-Dimensional Graphics Package for Fluid Dynamics Calculations," P. Morawski, NSRDC Report CMD-15-75 (Aug 1975).

forward and aft. The acoustically active faces of these four flats are only 6 in. (15.24 cm) in diameter. The basic housing as represented by quadrilateral is shown in Figure 4a.

The second body analyzed has the same geometry as the basic housing except that it does not have any flats (circular segment of a 17 in. (43.18 cm) sphere with a base diameter of 25 in. (63.5 cm) and a height of 5.478 in. (13.91 cm)). This body was analyzed because it was felt that the edges created by the flats created large pressure gradients. This body is shown as represented with quadrilaterals in Figure 4b.

The third body analyzed is a large fairing made to fit over the basic housing. Its quadrilateral representative is shown in Figure 4c. Shown in Figure 4d is the geometry and relative location of this large fairing. The size and shape of this body was determined by several factors: one, it should be smooth; two, it is meant to be placed over the basic housing; and three, it has to be large enough to delay separation until after the flow has passed over the acoustically active face (assuming the beam travels in a straight line from the housing and through the fairing). The size is determined from these facts and a "rule of thumb" that flow around a body will not separate if the slope is 15 deg or less.

RESULTS AND DISCUSSION

Hydrodynamic evaluation of the Sperry Projector Array housing in the water tunnel in its normal orientation revealed a separated region covering the aft lens face. This region was detected with dye and bubbles and remained basically unchanged for velocities between 4 and 16 knots. Bubbles injected into the flow ahead of the housing or just aft of the housing found their way into the separated region and gathered there as shown in Figure 5 (for 4.0 knots). This figure shows the bubbles injected in front of the body with their trajectory around the body and into the wake (flow direction is from left to right).

The potential flow streamline and isobar plots for the basic housing in the normal orientation are shown in Figure 6. Since no wake areas are

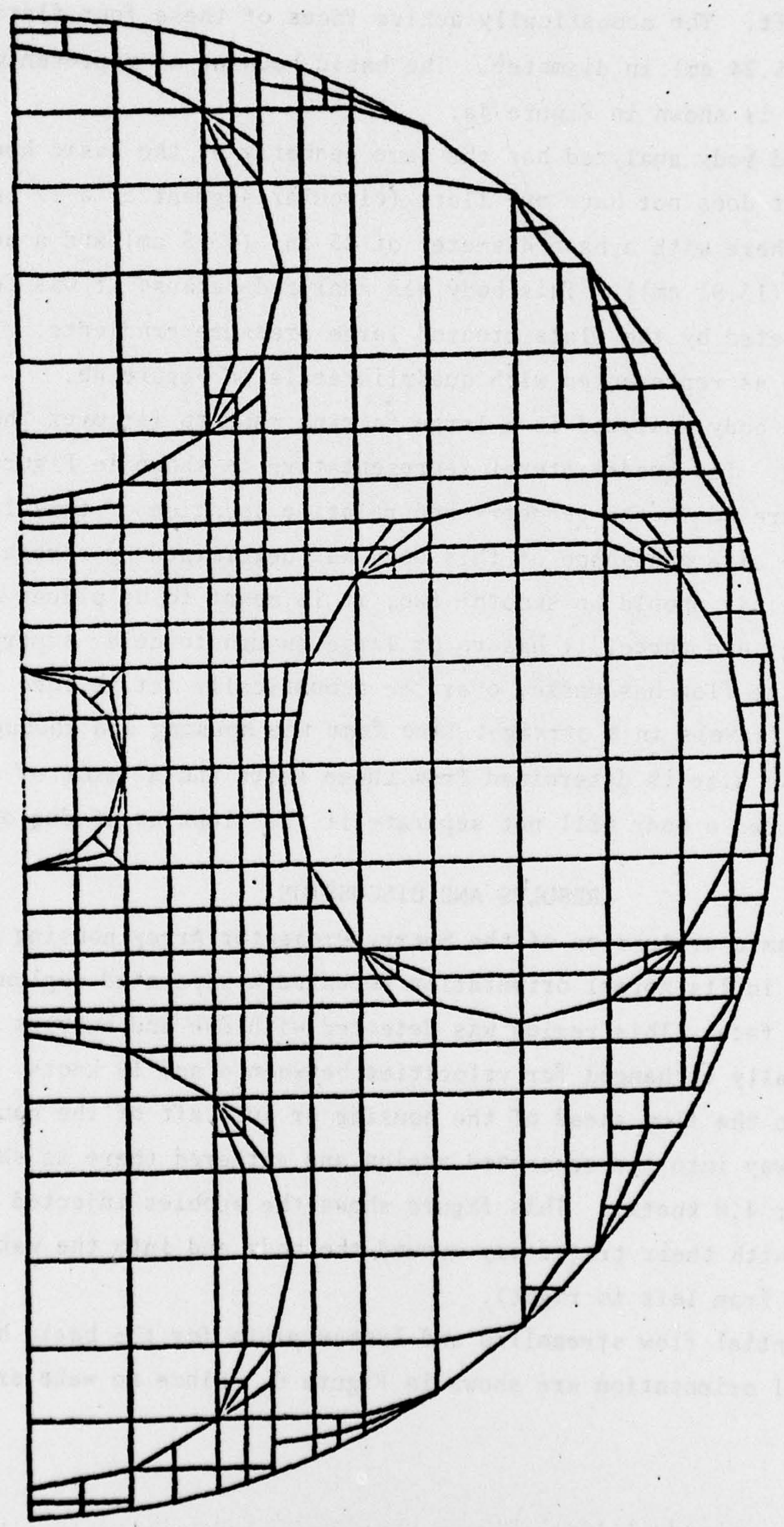

Figure 4a - Quadrilateral Representation of Basic Housing

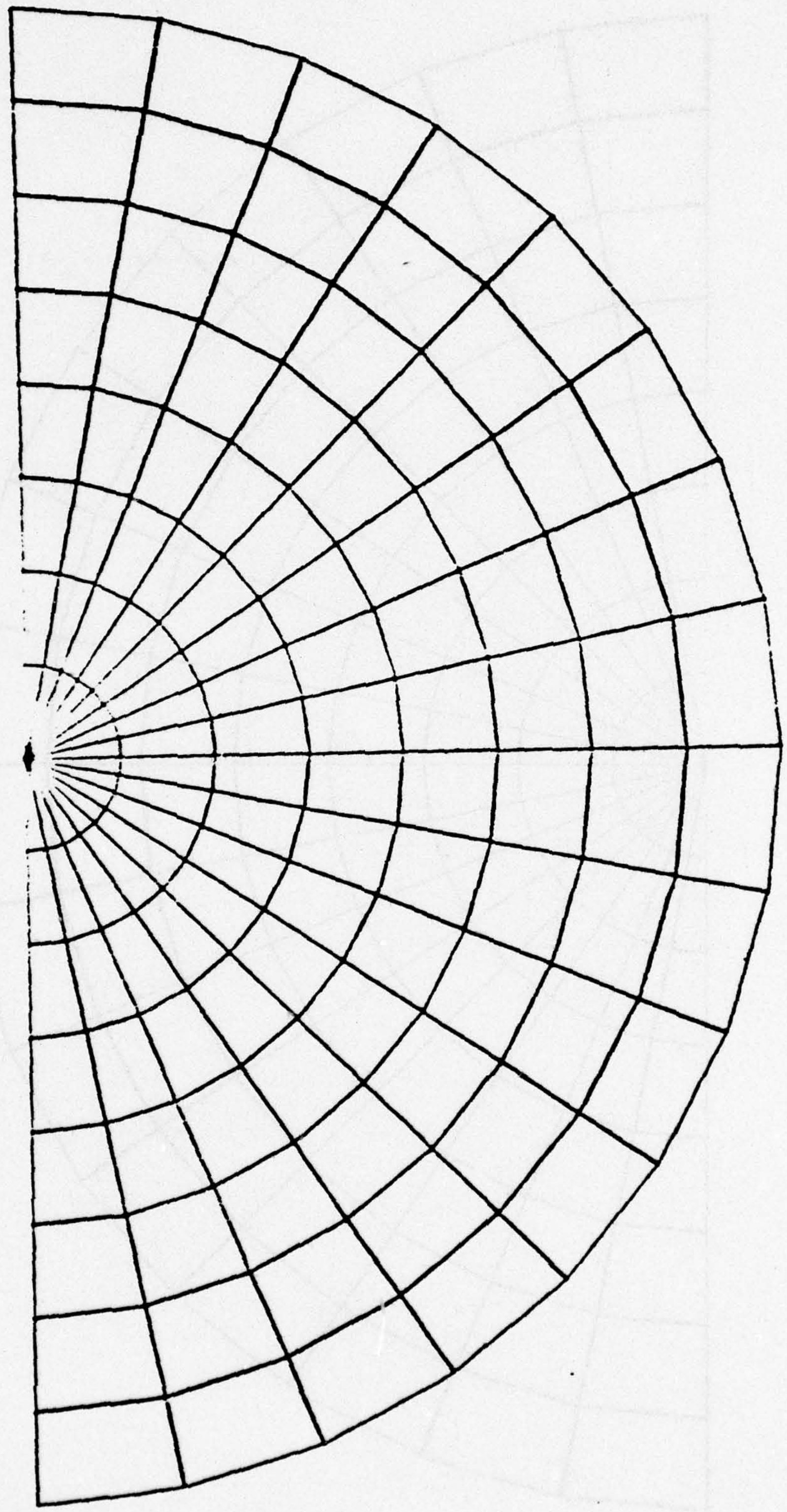

Figure 4b - Quadrilateral Representation of Basic Housing Without Flats

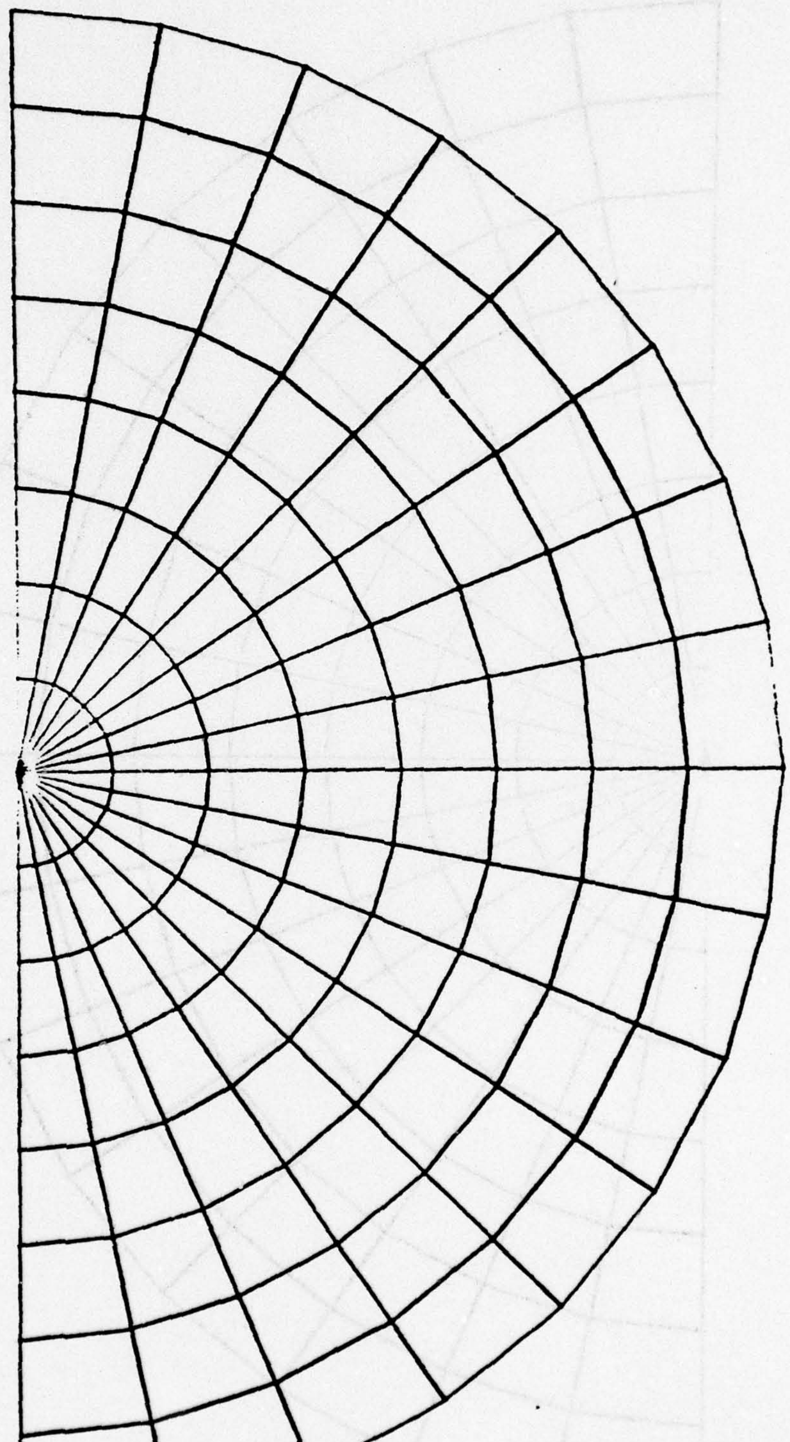

Figure 4c - Quadrilateral Representation of Large Fairing

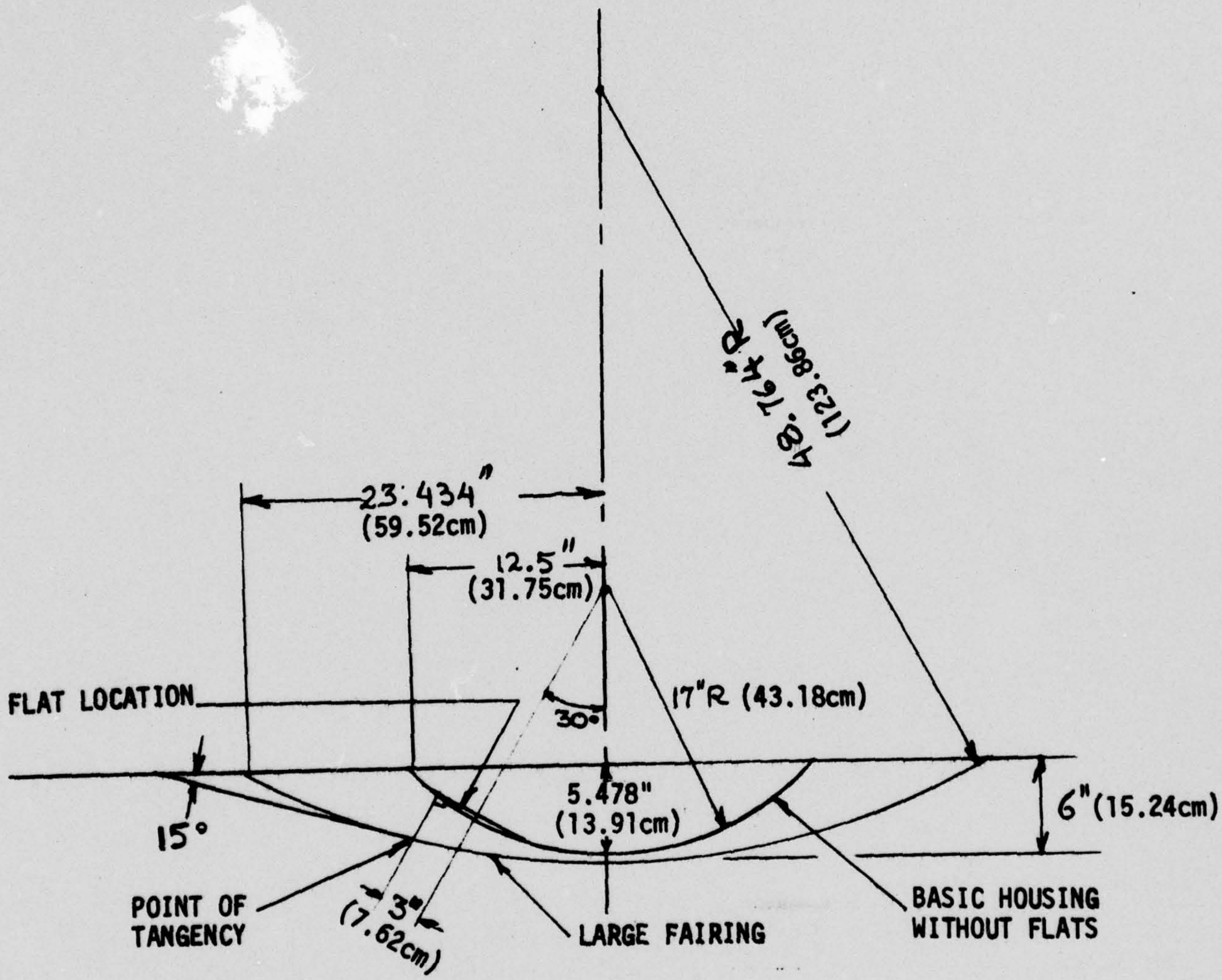

Figure 4d - Large Fairing Radius Determination and Relative Position

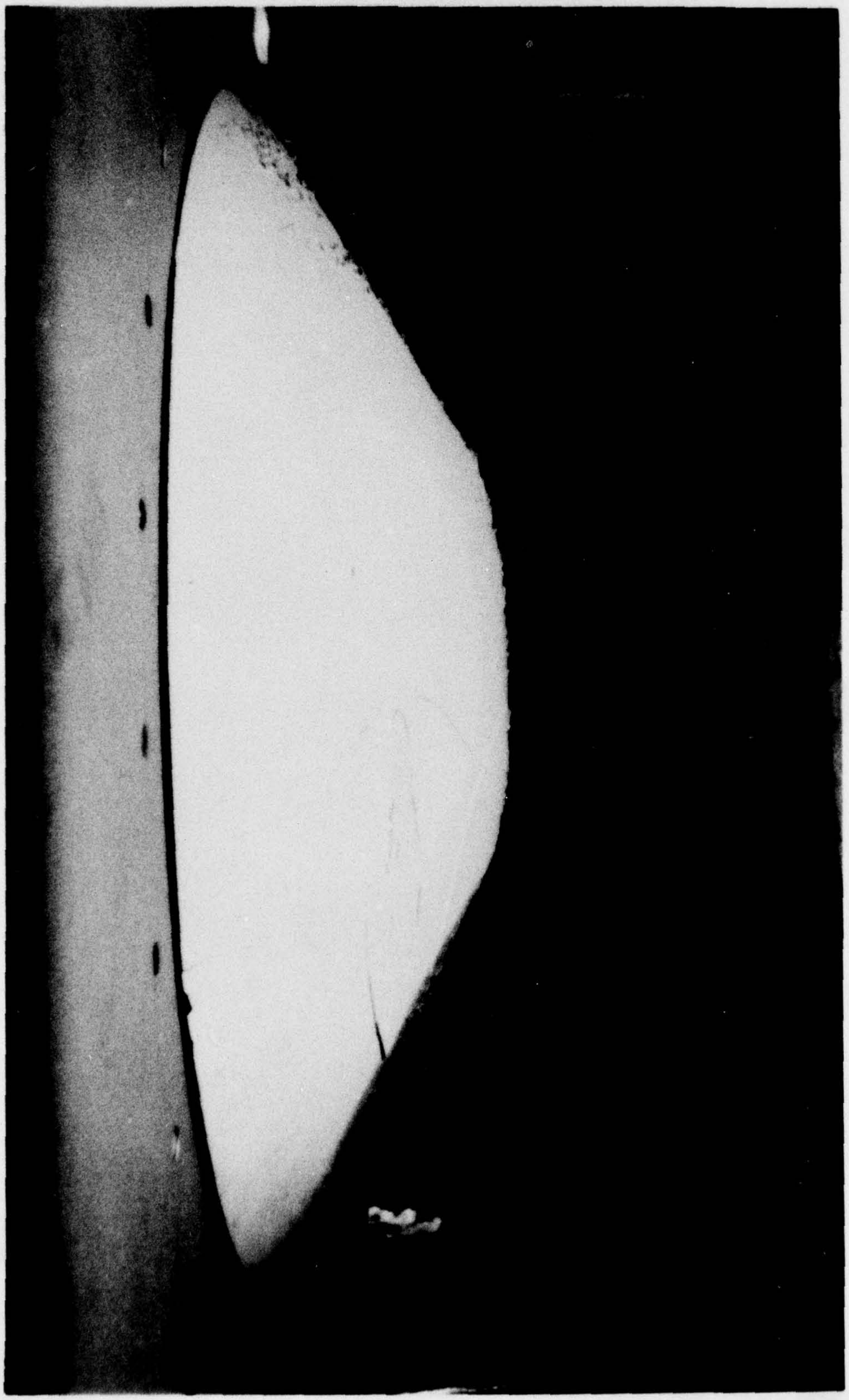

Figure 5 - Basic Housing: Bubbles Ejected From Forward Hole (4 Knots)

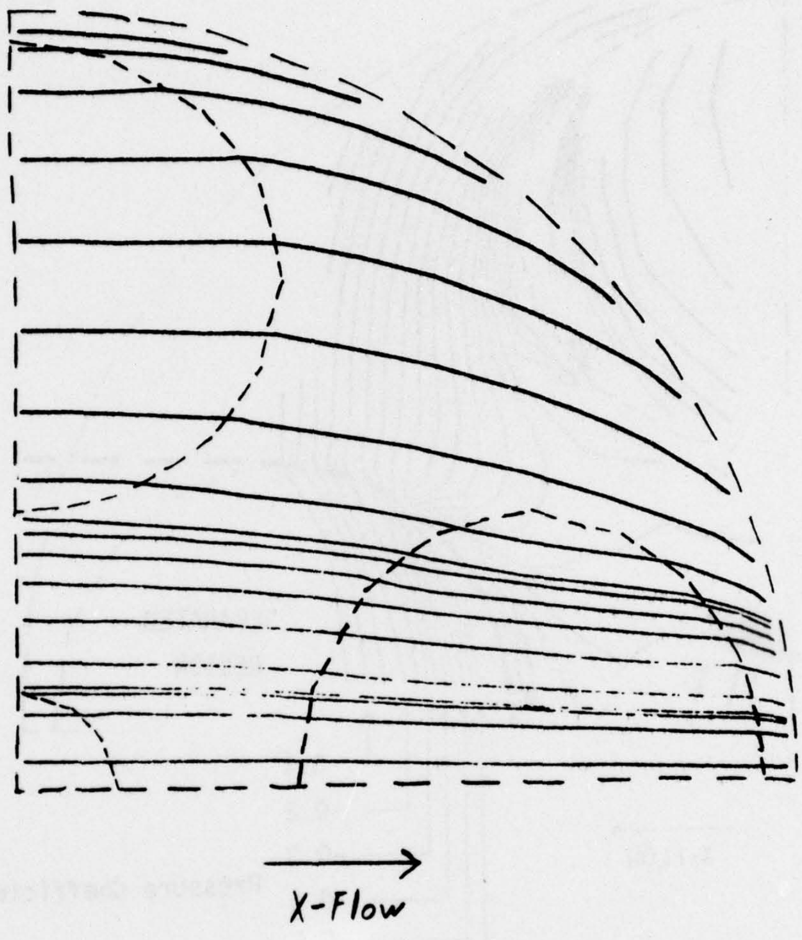

Figure 6a - Streamlines for X-Flow Over Basic Housing

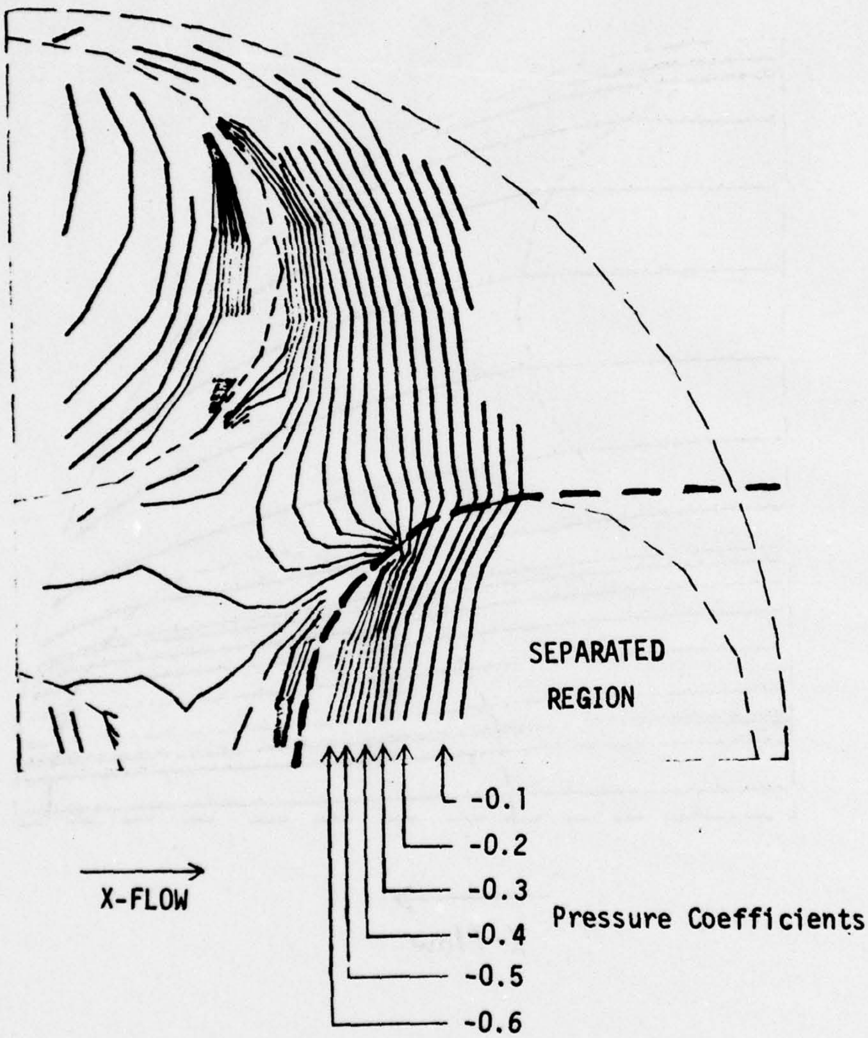

Figure 6b - Isobars for X-Flow Over Basic Housing

assumed in potential flow, the flow is symmetrical forward-aft and port-starboard. Thus, for convenience, only a quarter of the housing is shown. Notice that the streamlines curve near the intersection of the flats with the curved spherical surface. By following a streamline and observing the spacing of the isobars, the pressure gradients that the flow "sees" along that streamline are indicated. The flow over the forward half of the body generally shows a decreasing pressure. This is termed a "favorable" pressure gradient, meaning flow separation will not occur.

Over the aft half of the body, the pressure increases, especially near the flat-curved surface intersections. In these regions of "unfavorable" pressure gradients, the flow is most apt to separate.*,[6] The experimentally observed separated region is shown outlined with a dashed line in Figure 6b.

The streamlines and isobars for the basic housing without flats are given in Figure 7. The unfavorable pressure gradients are not as severe as those for the basic housing with flats. However, it is felt that they are severe enough to cause separation over part of the aft end. This separation region would be the largest for the lowest velocity (4 knots) and would be reduced in size (but always be present) for increasing velocities up to the maximum velocity (16 knots).

By making the housing large enough, it is possible to eliminate separation or to move it far enough aft so that it is not a problem. For example, a larger fairing was designed which would move the separated region aft of any interference with the aft projector beam. Streamlines and isobars for this design are shown in Figure 8. Even though this design would probably work to reduce the effect of the separated region, this large fairing is impractical for the present situation (mostly due to problems of acoustic transmission through the fairing and space requirements on the ship).

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*Separation depends on the development of the boundary layer as well as the pressure gradient. For more information, see Reference 6.

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[6] Boundary Layer Theory, H. Schlichting, McGraw-Hill, New York (1955).

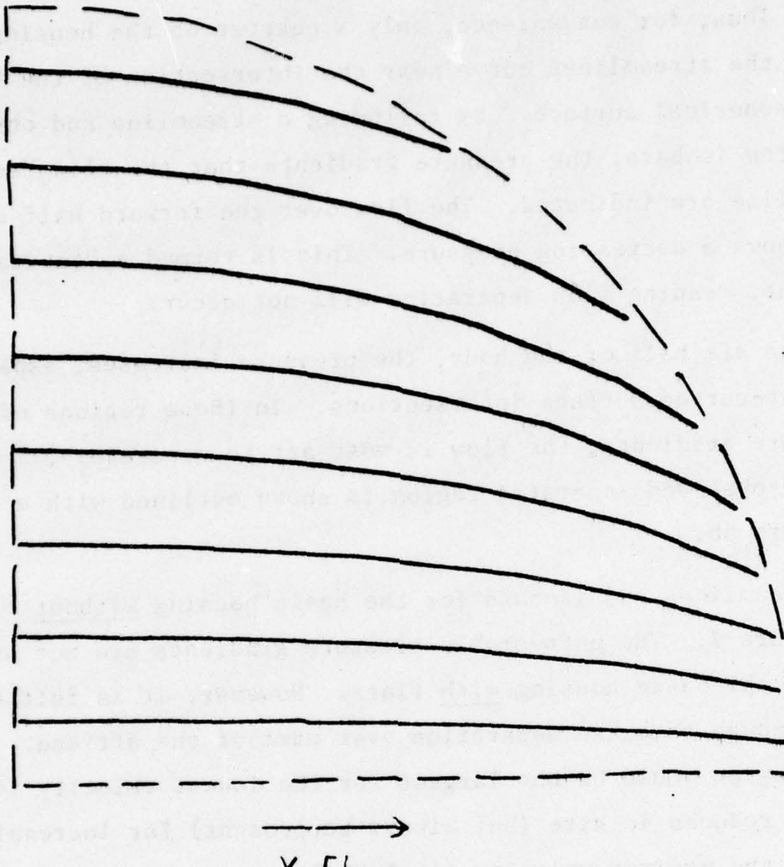

Figure 7a - Streamlines for X-Flow Over Basic Housing Without Flats

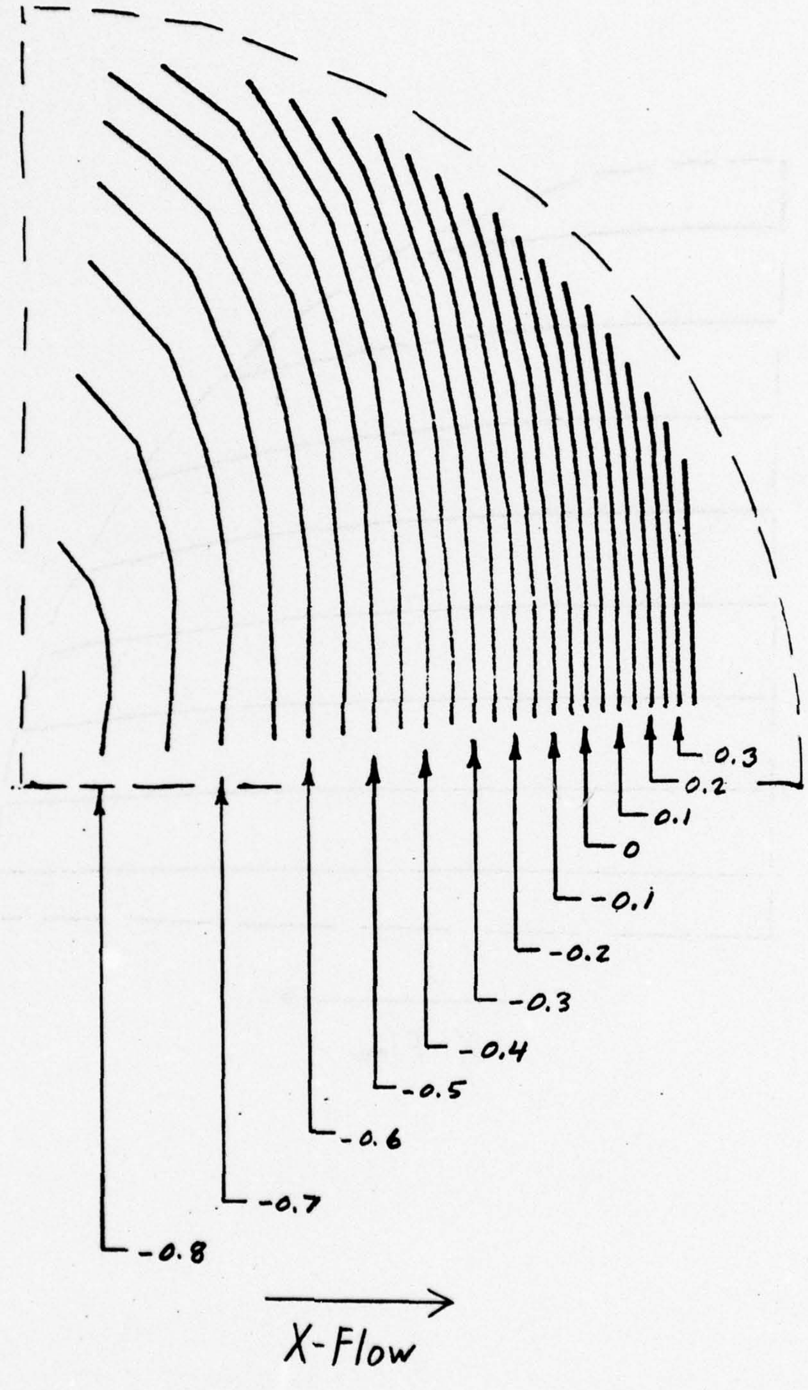

Figure 7b - Isobars for X-Flow Over Basic Housing Without Flats

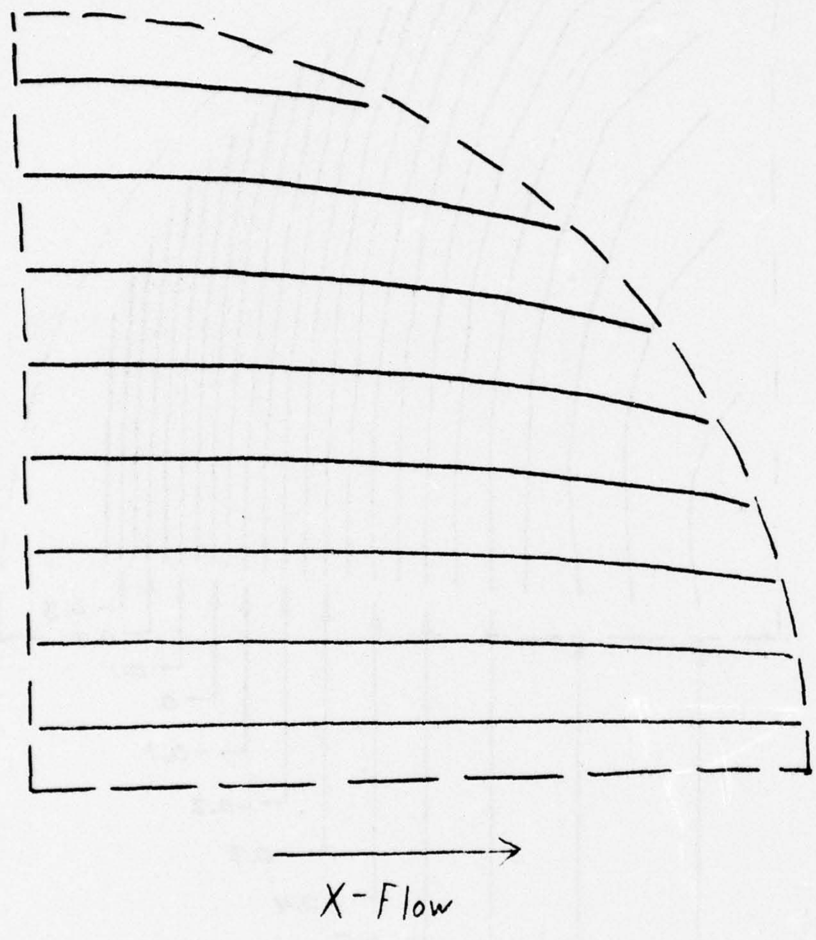

Figure 8a - Streamlines for X-Flow Over Large Fairing

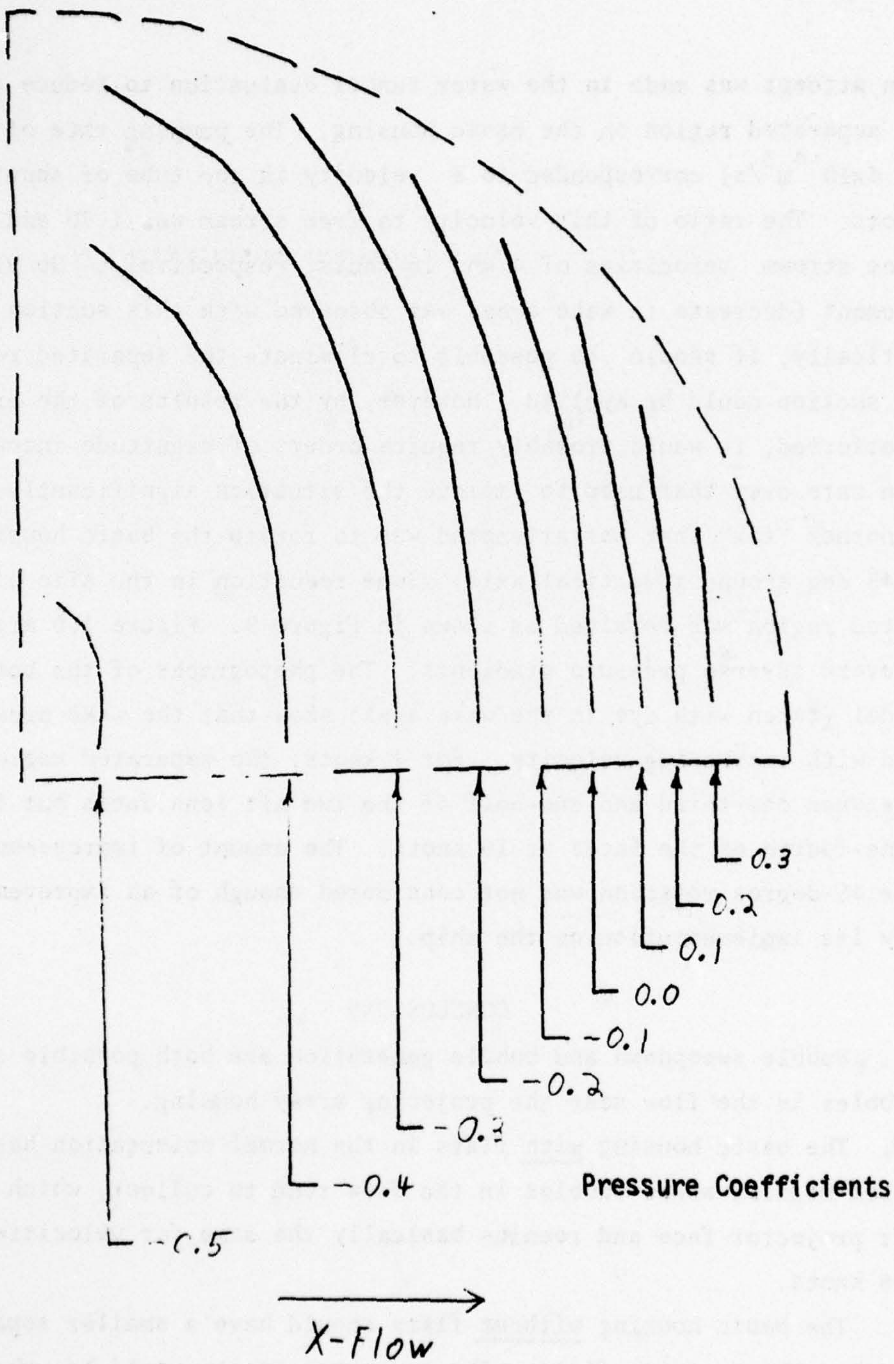

Figure 8b - Isobars for X-Flow Over Large Fairing

An attempt was made in the water tunnel evaluation to reduce the size of the separated region on the basic housing. The pumping rate of 7 gal/min ($4.4 \times 10^{-4} m^3/s$) corresponded to a velocity in the tube of about 6.8 knots. The ratio of this velocity to free stream was 1.70 and 0.42 for free stream velocities of 4 and 16 knots, respectively. No visible improvement (decrease in wake area) was observed with this suction rate. Theoretically, it should be possible to eliminate the separated region if enough suction could be applied. However, by the results of the experiment performed, it would probably require orders of magnitude increase in suction rate over that used to improve the situation significantly.

Another "fix" that was attempted was to rotate the basic housing with flats 45 deg around a vertical axis. Some reduction in the size of the separated region was obtained as shown in Figure 9. Figure 10b also shows less severe adverse pressure gradients. The photographs of the bottom of the model (taken with dye in the wake area) show that the wake area is reduced with increasing velocity. For 4 knots, the separated region covered between one-third and one-half of the two aft lens faces but less than one-fourth of the faces at 16 knots. The amount of improvement shown for the 45-degree rotation was not considered enough of an improvement to justify its implementation on the ship.*

CONCLUSIONS

1. Bubble sweepdown and bubble generation are both possible sources for bubbles in the flow near the projector array housing.

2. The basic housing with flats in the normal orientation has a separated region, where bubbles in the flow tend to collect, which covers the aft projector face and remains basically the same for velocities from 4 to 16 knots.

3. The basic housing without flats should have a smaller separated region than the one with flats. The separated region would be the largest at 4 knots and decrease in size as the velocity is increased, but still cover a portion of the projector face area at 16 knots.

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*This is a judgment made by Sperry personnel.

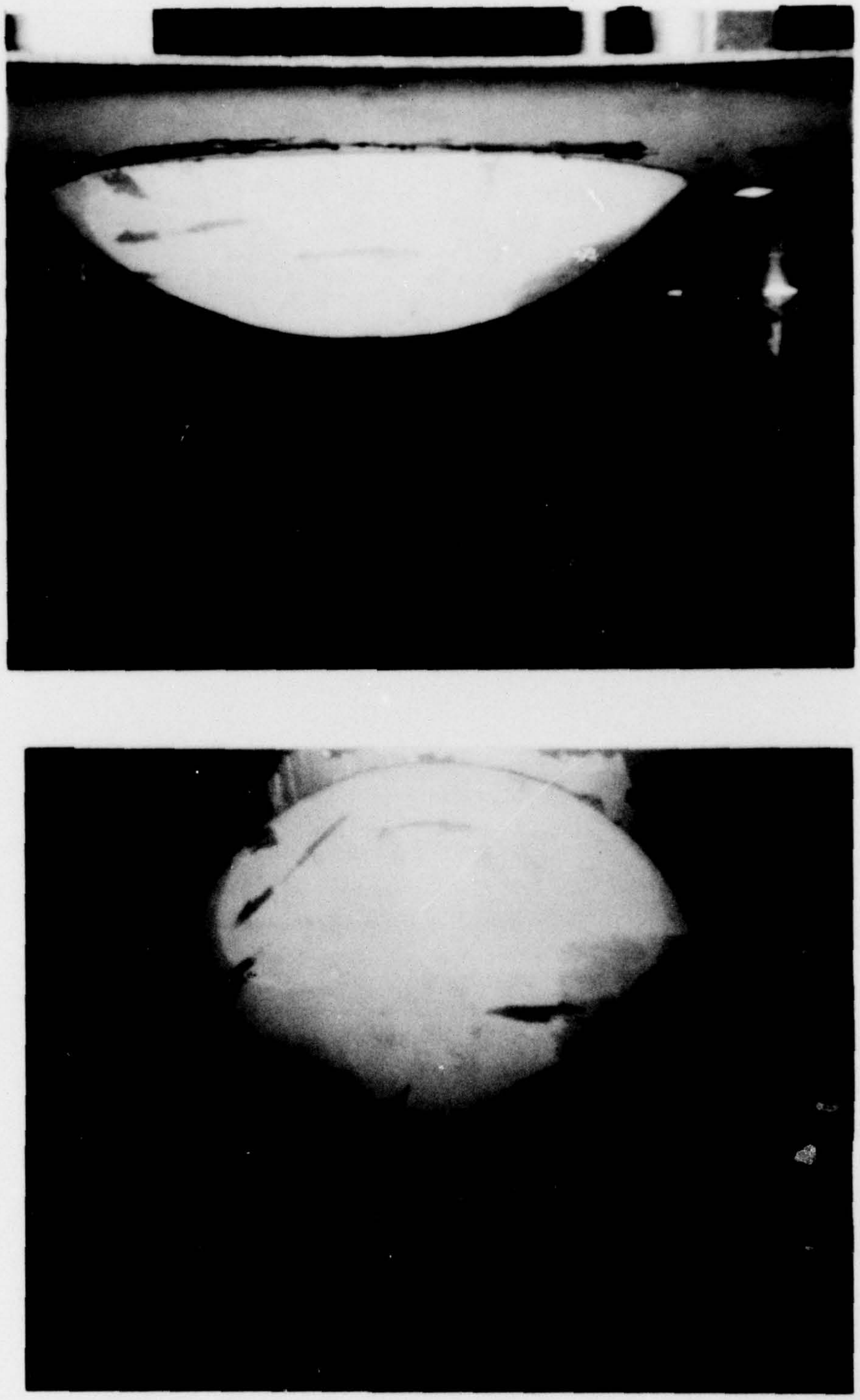

Figure 9a - Basic Housing Rotated 45 deg Under Dye Test (4 Knots)

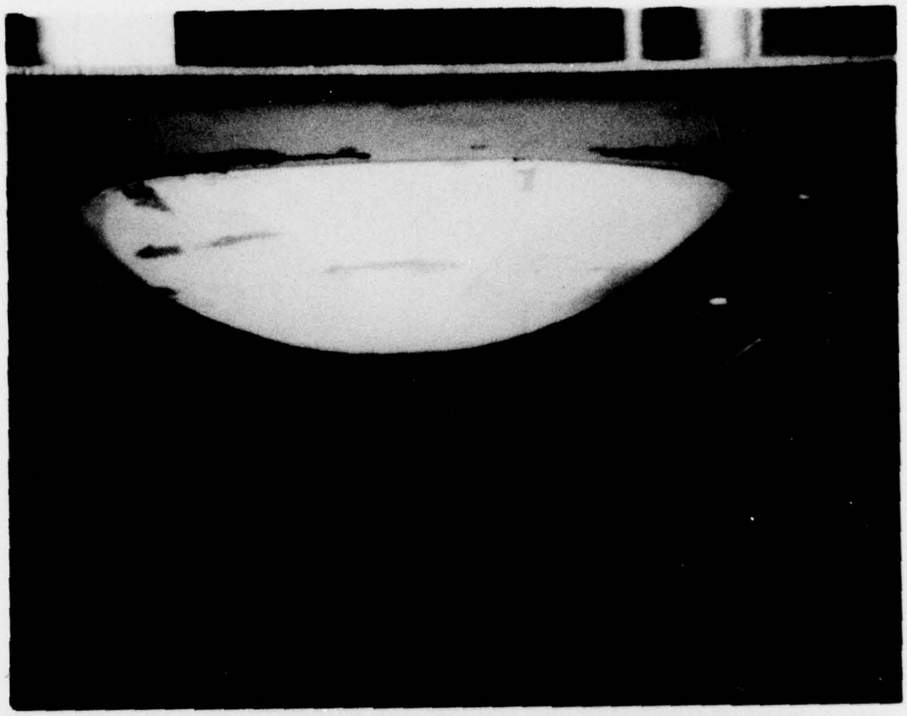

Figure 9b - Basic Housing Rotated 45 deg Under Dye Test (16 Knots)

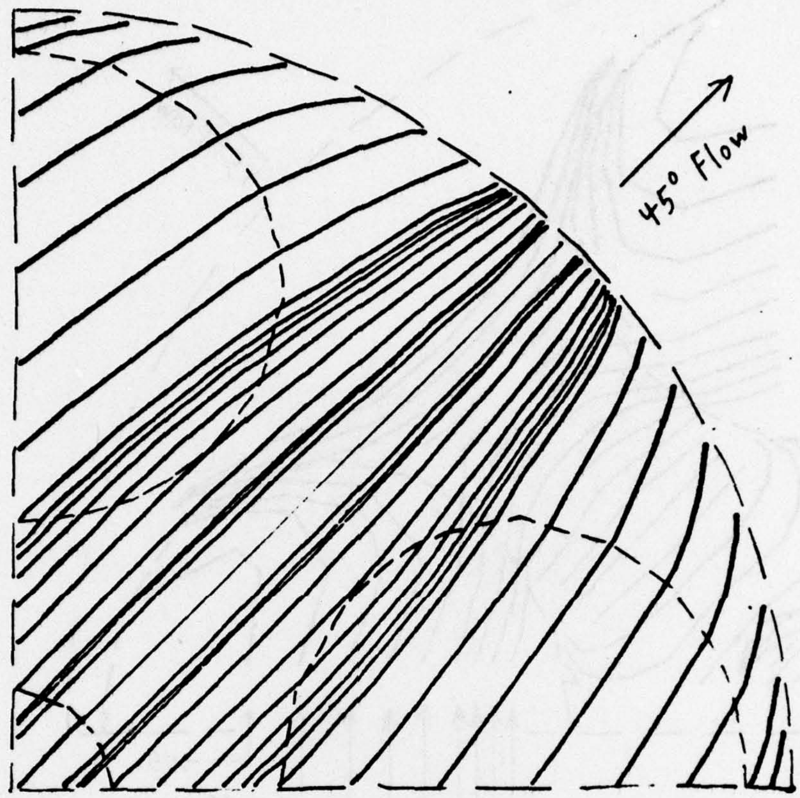

Figure 10a - Streamlines for 45 Degree Flow Over Basic Housing

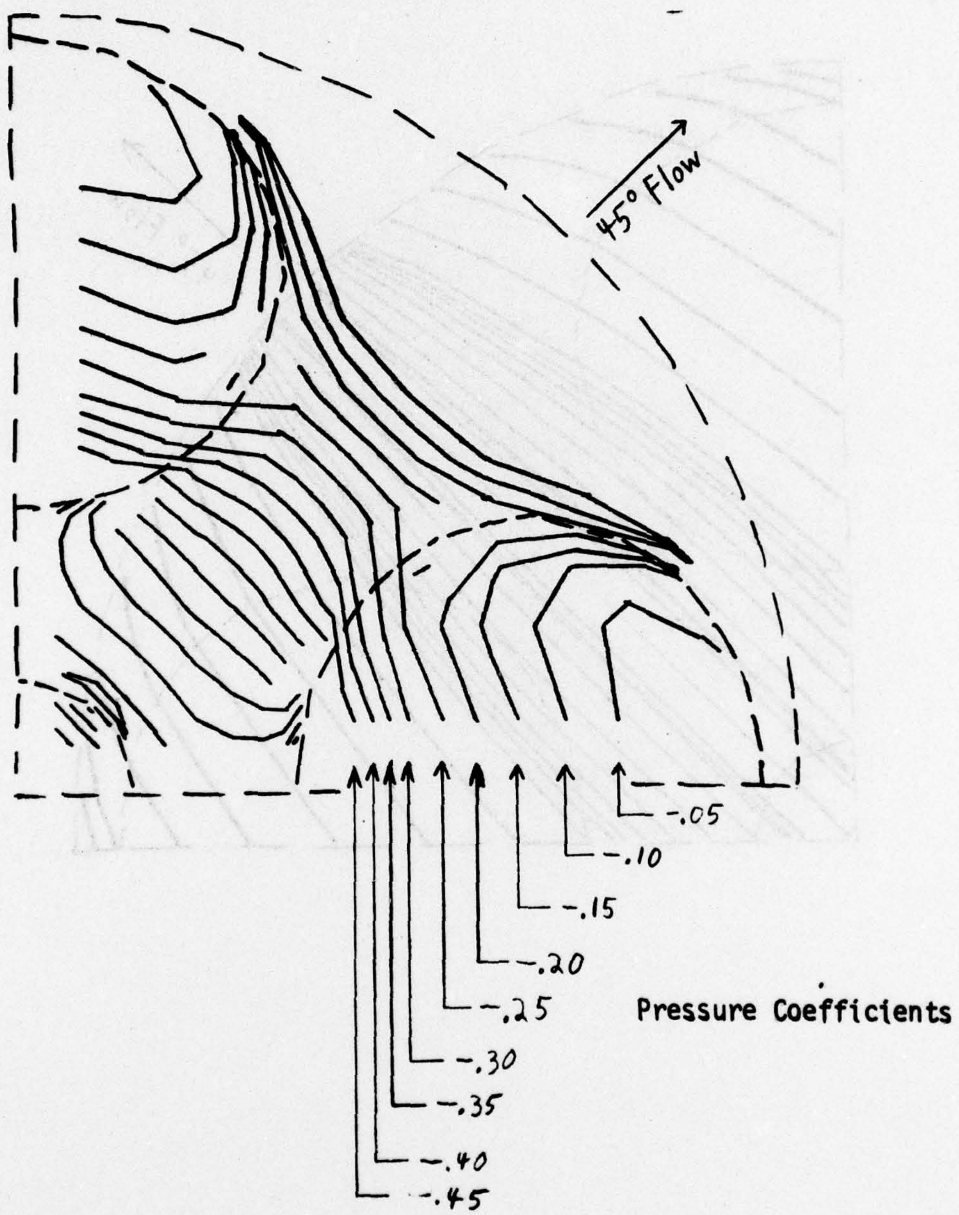

Figure 10b - Isobars for 45 Degree Flow Over Basic Housing

4. The large fairing that was designed should move the separated region far enough aft so that it would not affect the aft projector beam.

5. Suction up to 7 gal/min ($4.4 \times 10^{-4} m^3/s$) near the trailing edge of the housing has little effect on the size and shape of the separated region.

6. Rotating the housing to 45 deg would result in a somewhat smaller separated region than the normal orientation. The size of the region decreases with increasing velocity but still covers part of the two aft projector faces at 16 knots.

RECOMMENDATIONS

1. In order to move the separated region aft of the projector beam, it is recommended that a large fairing similar to the one designed be used.

2. A model of whatever design is used should be verified experimentally for separation before the prototype is installed on the ship.

ACKNOWLEDGEMENTS

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APPENDIX A

PARTIAL FLOW LINES ON MARINER CLASS HULLS FROM UNPUBLISHED DTNSRDC DATA

The photographs of this appendix are from unpublished DTNSRDC model experiments and show some flow lines over the model hull of the Mariner Class ship. Although there may be minor differences in the rudder from the Compass Island, the results are not affected significantly for the flow over the forward part of the hull.

The flow lines shown in Figures A1-A3 have been transferred to the body plan of Figure A4. The approximate location of the Sperry Projector Array housing is indicated by an arrow near B-5 and the Station 7 line (185 ft = 56 m).

These few lines of flow indicate a definite tendency for flow from the bow to pass under the ship in the vicinity of the housing.

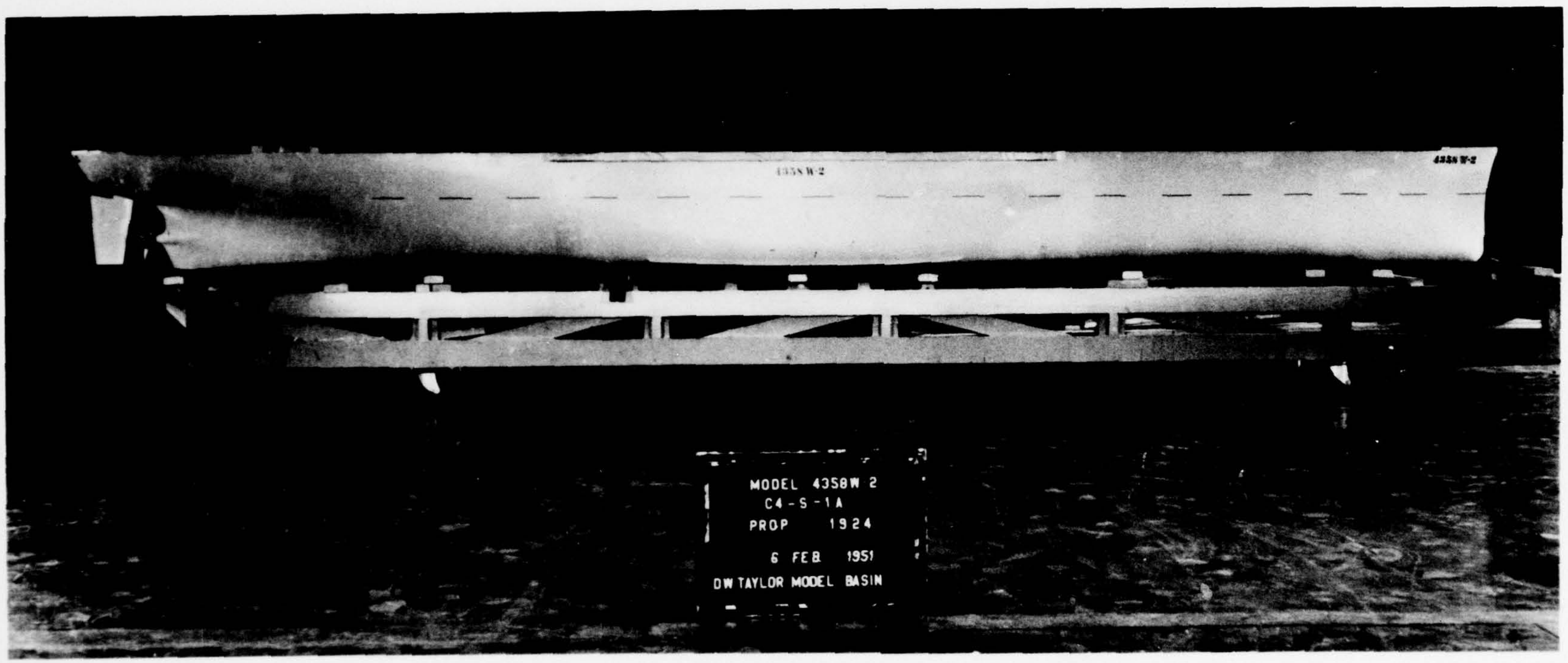

Figure A1 - Beam View of Ship Model

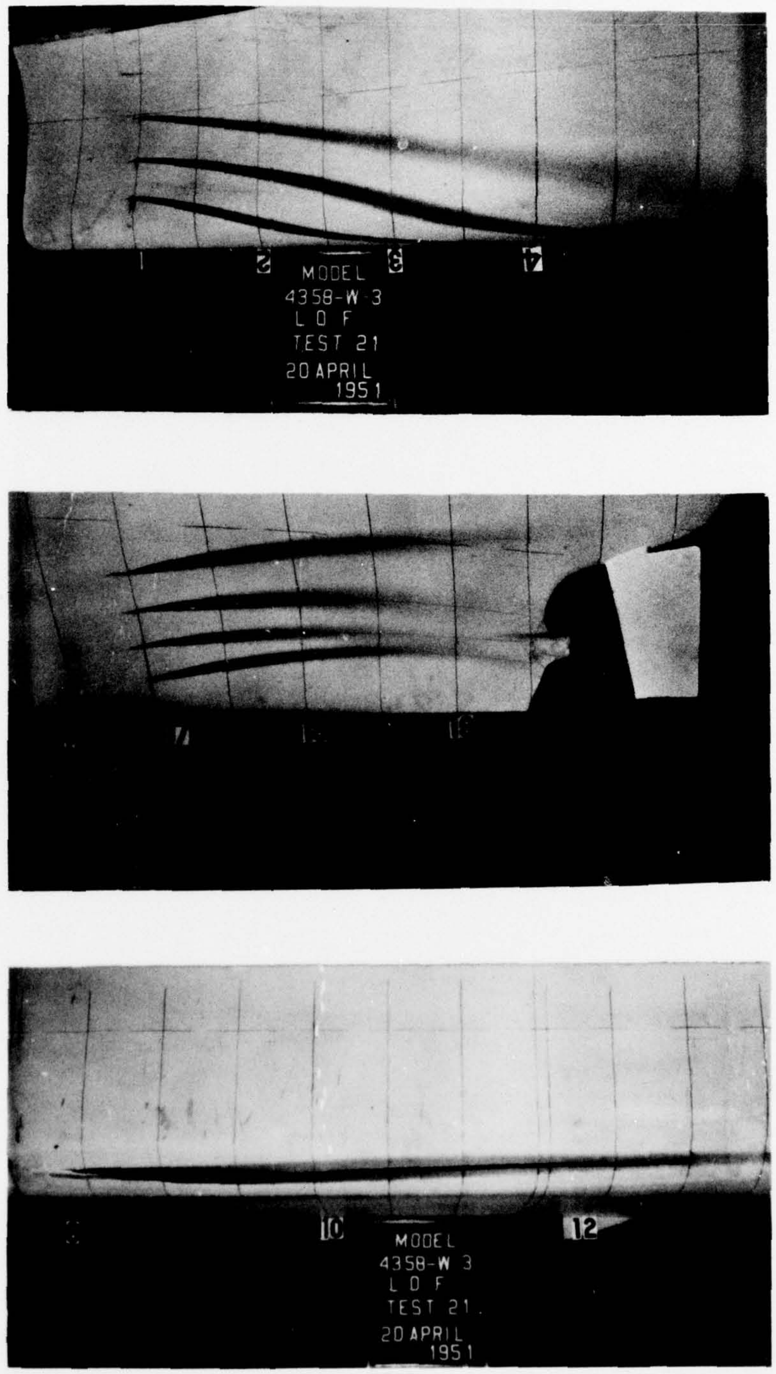

Figure A2 - Lines of Flow from Model Tests

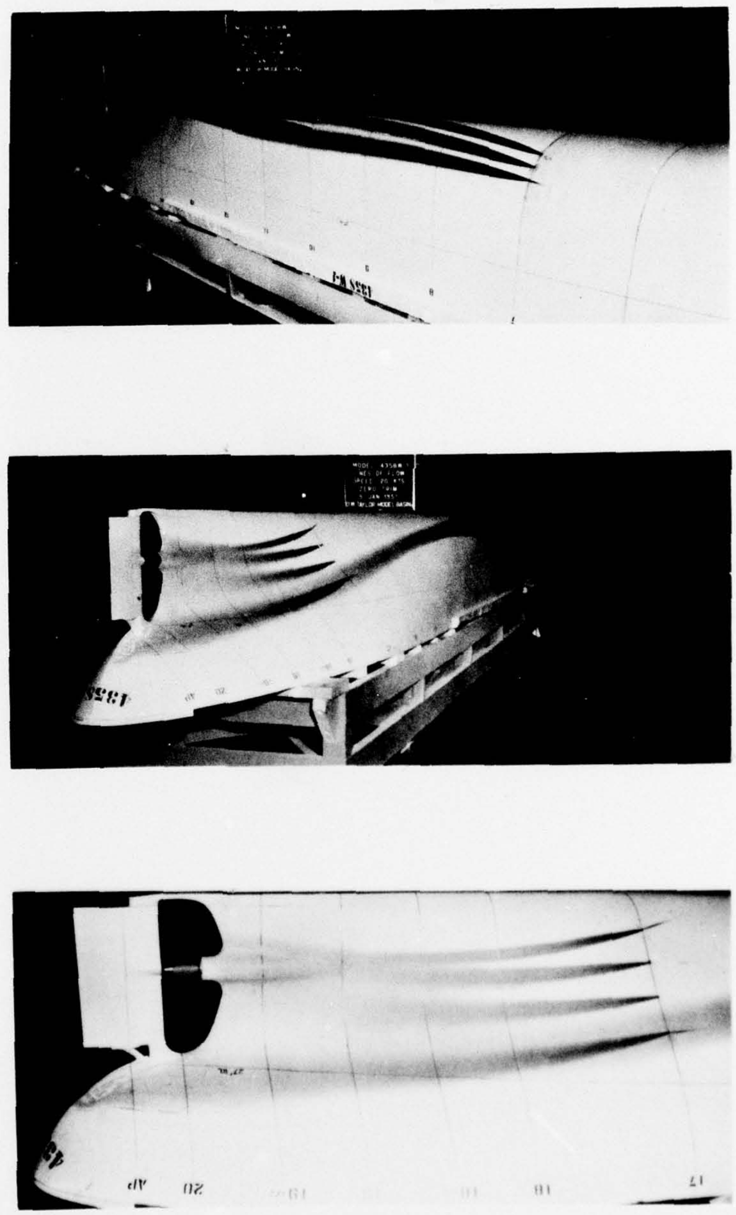

Figure A3 - Lines of Flow from Model Tests

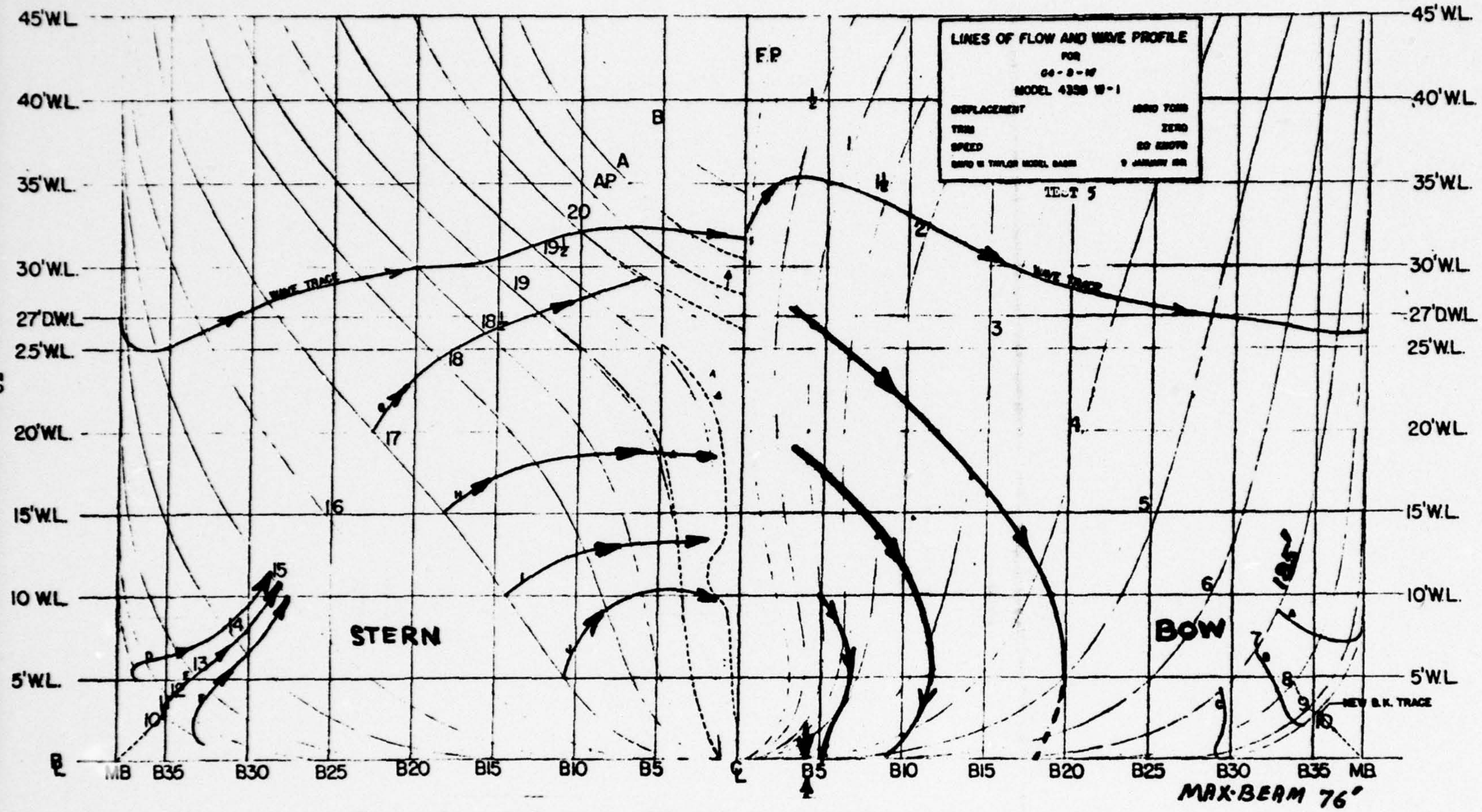

Figure A4 - Body Plan of Model Showing Flow Lines

APPENDIX B

PRESSURE CALCULATIONS

In this report, pressure data have been presented in coefficient form. This is done since, for potential flow, the pressure coefficient is independent of the magnitude of velocity and only a function of geometry. In a real-flow situation, the pressure coefficient varies with velocity (Reynolds number). However, for many cases, as is the case here, the minimum pressure coefficient determined from potential flow is a good representation of the real flow minimum.

In this appendix, the relationship between coefficient and absolute pressure is given. To obtain one from the other, an example is given which is of special interest to the bubble generation question.

Suppose the surface water which has some dissolved gas is pulled down under the ship as indicated as likely by the information in Appendix A. In order for this water to release the gas, its pressure must be lower than that of the undisturbed surface water (atmospheric pressure). As the water is pulled down around the ship, its velocity increases as it flows around the ship or any protuberances (in this case, a housing). This increase in velocity will tend to decrease the pressure. At the same time, any increase in depth will increase the static pressure. When these two effects cancel each other, atmospheric pressure will result. The value of the pressure coefficient for this to occur is a function of velocity and may be calculated for a depth of 25 ft (7.62m) as follows:

$$C_p = (P-P_\infty)/((1/2)\rho U_\infty^2)$$

where C_p is pressure coefficient

P is pressure

P_∞ is free-stream static pressure

ρ is density

U_∞ is free-stream velocity

In this example case,

$$P = P_{atm}$$

$$P_\infty = P_{atm} + \gamma h$$

where P_{atm} is atmospheric pressure

γ is weight density $= \rho g$

h is depth

Thus,

$$C_p = \left[P_{atm} - (P_{atm} + \gamma h)\right] / ((1/2)\rho U_\infty^{\ 2})$$

$$= -\gamma h / ((1/2)\rho U_\infty^{\ 2})$$

$$= -2gh/U_\infty^{\ 2}$$

For a depth (h) of 25 ft (7.62m), this equation is plotted in Figure B1. It is seen that to have atmospheric pressure on the bottom of the ship (25 ft or 7.62m) at 8 knots would require an extremely large negative pressure coefficient of about -9. From the report, the minimum coefficient for the basic housing alone was about -1.4. This would require a velocity of about 20 knots to have surface water obtain atmospheric pressure of the minimum pressure point on the bottom of the housing. Remember, however, that there would be an added lowering of the C_p due to the flow around the ship. This would tend to decrease the required velocity to something less than 20 knots. Also, here only surface water was considered. If water with dissolved gas initially at some other depth were considered, here again, this would lower the required velocity.

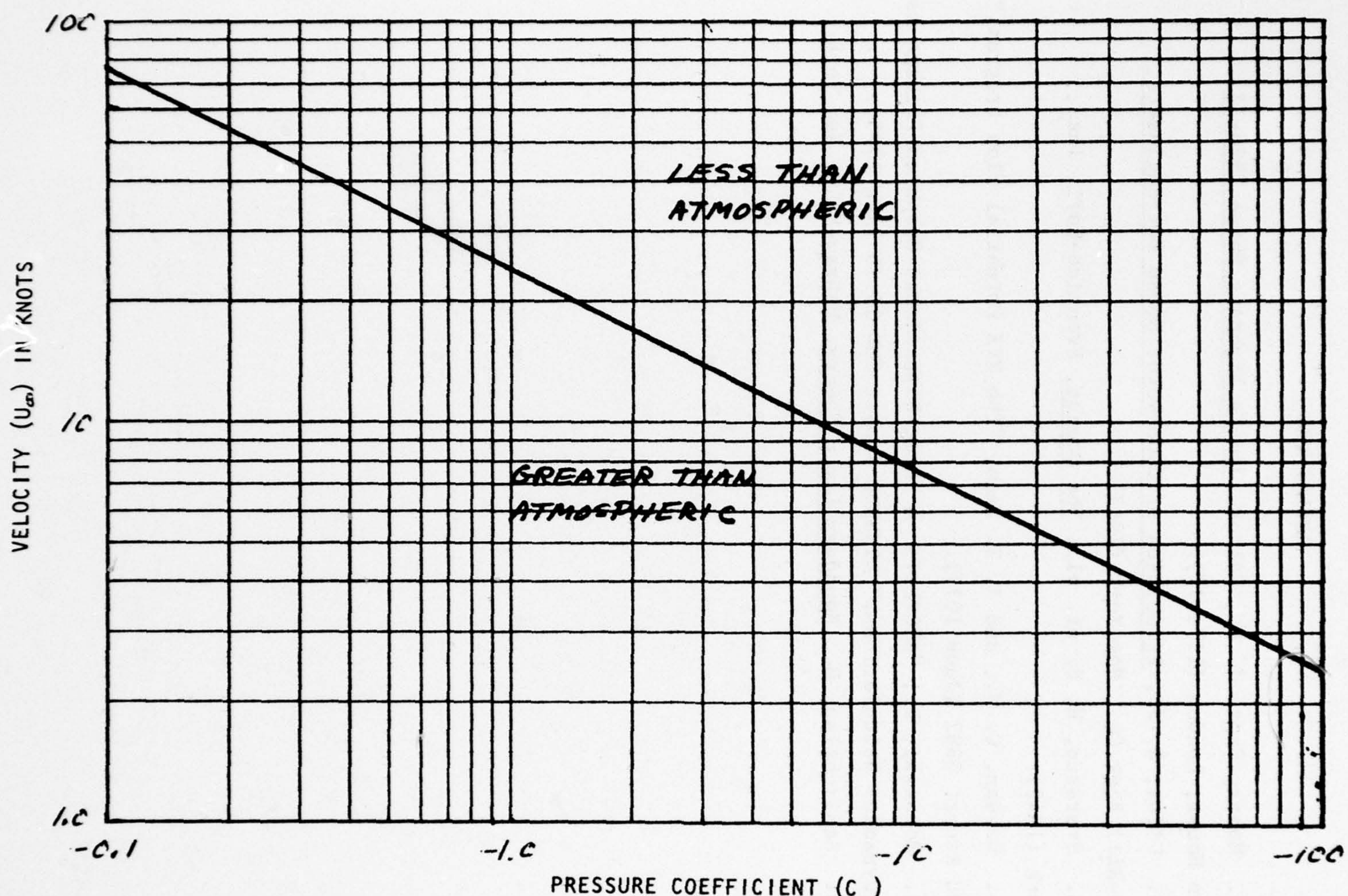

FIGURE B1 - RELATIONSHIP BETWEEN SHIP VELOCITY AND PRESSURE COEFFICIENT TO OBTAIN ATMOSPHERIC PRESSURE AT A DEPTH OF 25 FT (7.62 M)

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